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CEBAF SUPERCONDUCTING CAVITY RF DRIVE SYSTEM

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INTRODUCTION

The CEBAF RF system consists of 418 individual RF amplifier chains. Each superconducting cavity is phase locked to the master drive reference line to within 1 degree, and the cavity field gradient is regulated to within 1 part in 10^4 by a state-of-the-art RF control module. Precision, continuously adjustable, modulo 360° phase shifters are used to generate the individual phase references, and a compensated RF detector is used for level feedback. The close coupled digital system enhances system accuracy, provides self-calibration, and continuously checks the system for malfunction. Calibration curves, the operating program, and system history are stored in an on board EEPROM.

The RF power is generated by a 5Kw, water cooled, permanent magnet focused klystron. The klystrons are clustered in groups of 8 and powered from a common supply. RF power is transmitted to the accelerator sections by semiflexible waveguide.

REFERENCE RF DRIVE LINE

The injector, the superconducting linacs, and the RF separators are served by an ultra stable RF reference drive line. This transmission line is accurately temperature stabilized and evacuated. An interferometer is installed to continuously measure and control its electrical length.[1] The computer control system [2] drives a mechanical phase shifter in the line to continuously correct its overall electrical length. The linac drive lines have tap points (directional couplers) located every 10 meters. Each tap provides reference signals for 8 RF subsystems through an 8 way power divider.

RF CONTROL MODULE

The RF control module lies at the heart of the CEBAF RF system. The module contains all circuitry required for control, regulation, and monitoring of an individual RF chain. This includes klystron control and protection, accelerating cavity monitor, tuning and quench detection, beam permissive control (RF ready) and, of course, phase, gradient and frequency regulation of each cavity. The controller is fabricated in a standard 3 wide CAMAC module for system standardization and ease of maintenance.

A large amount of local computing capability will be provided to reduce the programming costs and enhance accuracy. Full use is being made of self test circuitry and "expert systems" maintenance and repair concepts. Linearization tables, system constants, module calibration curves, analog parameters and maintenance history will be stored in onboard EEPROM memory, and become permanent record in each individual module. All first line maintenance will be by module replacement, the failed modules will then be repaired and calibrated using automatic test equipment at our central maintenance facility.

PARAMETER LIST:

ACCELERATOR:

Number of cavities	418
Type	Superconducting
Cells per cavity	5
Average field gradient	5 MV meter
Maximum field gradient	9 MV meter
Output energy	4-6 GeV
Number of passes	4

KLYSTRON

Number on line	418
Location	Klystron Gallery
Output power	5 KW max
Focusing	Permanent magnet
Control	Mod anode
Cooling	Water
Beam power supply	100 KW (8 Klystrons)
Beam voltage	10 KV
Frequency	1497 MHz
Maximum VSWR	50:1

TRANSMISSION LINE:

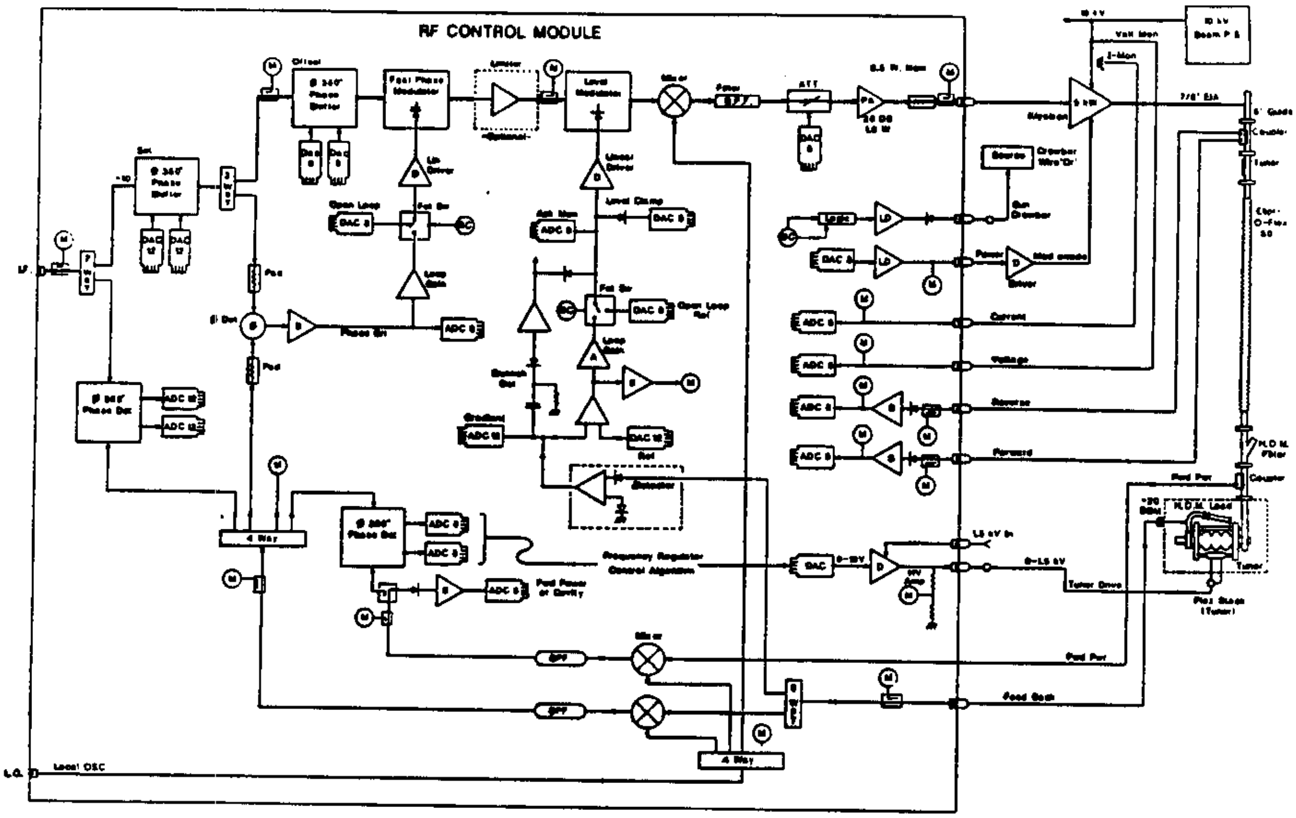
Type	Flexible waveguide
Size	1/2 high WR-650
Length	15 meters
Loss, typical	0.5 DB

CONTROL AND REGULATION:

Field gradient toll.	1×10^{-4}
Phase regulation	1 Degree

The control module is required to provide phase setability and regulation of the cavity RF phase to better than 1°. To achieve this ambitious goal, the 1.5 GHz feedback and reference signals are heterodyned to a more manageable IF frequency in the VHF band where high accuracy signal processing components are available and reasonably priced. The regulator uses a complex phasor modulator (CPM) to provide a smooth, precise, 360° unambiguous computer generated phase reference, and a similar less precise device to remove accumulated phase offsets from the system. The fast phase regulator uses the traditional 90° nulling type phase detector and varactor modulator in a closed loop servo regulator.

The fast RF amplitude regulator uses a conventional analog control loop with a fast compensated RF level detector for feedback, and a 12 bit DAC as the reference. A slow amplitude control loop continuously keeps the fast loop centered in range to adjusting the klystron mod anode voltage and the drive level attenuator.



RF CONTROL SYSTEM

The cavity quench detector is an integral part of the level regulator. When the cavity drive is removed the voltage in the cavity normally falls at a rate set by the system Q, but during a cavity quench the fall time can be much shorter. Any fast negative excursion of the cavity voltage will be interpreted as a quench, the RF drive will be immediately removed, and the injector gun inhibited. After a few seconds the computer will reestablish the cavity voltage and ramp the beam current back to the previous operating level. If a given cavity continues to break down or quench, its operating gradient will be automatically reduced by the central RF control computer, and the difference made up in nearby cavities.

The Kapton windows in the prototype cavities are protected from damage by a fast photodiode arc detector and a thermopile temperature indicator, each driving RF shutdown circuitry in the control module.

FREQUENCY REGULATOR

The frequency control system consists of a mechanically actuated tuner used to bring the cavities into the normal operating frequency range after cooldown. The electronic control circuit uses an unambiguous 360° phase detector to compare the phase of the incident cavity feed voltage with the phase of the actual voltage induced in the cavity. The RF control microcomputer uses this phase signal to compute cavity load impedance, and if required, readjust the mechanical tuner to return the cavity to resonance.

KLYSTRON AND TRANSMISSION LINE

With superconducting cavities the RF power load results almost entirely from accelerator beam loading and can fluctuate from full load to no load on a very short time scale. When beam is turned off or is adjusted to a small value the cavity looks like an open circuit at the end of the waveguide system. Under these conditions the VSWR will be extremely high, and unless the system is carefully designed, will cause window arcing and klystron instability. The cavity coupling is chosen such that the VSWR will drop to a matched condition when the accelerator is operating at full beam current. One could, of course, circumvent some of these problems by the installation of a ferrite circulator/isolator. The klystrons would then be operated at near full output and the excess power not required for particle acceleration would be dissipated in the circulator load. Unfortunately, the capital cost, as well as the operating cost for such a system would be high.

Our choice is to design the transmission line as a voltage matching resonant system, and specify the klystron such that it will couple properly to a wide range of impedances. The klystron output gap is placed an integral 1/2 wavelength from the superconducting cavity accelerating gap. This will lock the klystron gap voltage to the cavity accelerating voltage over the full range of accelerator beam current. The maximum voltage in the transmission line system will be the same for all beam loading conditions, and the klystron output gap voltage will never exceed the klystron beam voltage. When the accelerator is operating at reduced beam current, the mod anode regulator